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Accelerated Fuzzy PI Controlled SEPIC for Voltage Controlled Inverter

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Abstract: DC-DC converters plays major role in batter operated devices and adjustable speed drives. DC-DC converters may increase or decrease the output voltage. Size, cost and efficiency of the converters are important factors for selection of converters in an application. Single ended primary inductor converter is proposed in this study, for its output voltage control and less space consumption. The SEPIC converter is presented later on three phase diode rectifier for voltage stability. To enhance the DC voltage stability an intelligent fuzzy logic controller named Accelerated fuzzy PI controller is proposed in this study. The quality of the inverter voltage decides the efficiency of the load. In this study, fuzzy gain scheduling is proposed to control the PWM of the inverter. The total organization is analyzed using MATLAB.

Key words: SEPIC converter, inverter, fuzzy PI, accelerated, India

INTRODUCTION

Now a days, AC/DC rectifier is used for many applications such as adjustable speed drives, chargers for battery operated devices, etc. It is utilized in a broad range of ability. Three-phase bridge rectifiers are characterized by a nonlinear behavior because of the time-variant characteristic of their switching devices (diodes) and therefore, they hold the disadvantage of absorbing highly distorted AC line current, with large fifth and seventh harmonic components. Quality of DC or AC voltage decides the efficiency of the system. Control of switches in DC-DC converters plays vital role in output voltage.

Single-Ended Primary Inductor Converter (SEPIC) is a kind of buck boost converter capable of stepping up or down input voltage and belonging to the class of converter that has two inductors. It has the non-inverting characteristic of buck-boost converters. SEPIC converter as does cuk converter has the desirable feature of the switch controller minal being connected to ground; this simplifies the gate-drive circuitry. The converter also has non-pulsating input current (Rashid, 2001; Mohan *et al*., 2003).

The input currents of the cuk and SEPIC to topologies are continuous and they can draw ripple-free current from a DC source. SEPIC topology however is notably only applicable to applications where the battery voltage is higher than the DC source voltage (Chiang *et al*., 2009). The principle of SEPIC converter is based on buck boost converter so their characteristics are the same.

Lin and Huang (2009) discussed integrated SEPIC forward converter that uses synchronous switching technique for a PV-based LED lighting system. In charging mode and during day time, the SEPIC converter delivers solar energy to the battery bank via PV cell modules. At night and in discharging mode, soft-switching forward converter drives the LED lighting system.

Veerachary (2005) demonstrated voltage-based power tracking of nonlinear PV sources through coupled-inductor SEPIC converter which was capable of reducing array current ripple and improving converter efficiency. The proposed algorithm was implemented in real-time, aided by ADMC-401DSP evaluation module analog device. At racking, program was developed for an experiment with analog-to-digital converter (ADC) interrupt. The processor enabled tracking of the maximum power within 200 ms. Duran *et al*. (2009) exemplified the methodology and an experimental system based on interfaced SEPIC converters for measuring I–V and P–V curves of PV modules. To reduce curve ripple, four parallel-connected SEPIC converters and inter leaved operation mode we reused. The new development provided a new level of speed, portability and ease of measurement of peak power, in both the modules and the PV arrays.

Dos Santos *et al*. (2011) presented the computer simulations of a proposed system of integration of energy sources in which Triple Active Bridge (TAB) converter served as interface. The system had a load, a main voltage source and an auxiliary power source formed by a PV panel and a SEPIC converter. The TAB converter was fed voltage and it applied a method of decoupling loops for control of the voltage. The proposed system is applicable to UPS and micro-grids. Chiu *et al.* (2011) presented a high-intensity-discharge street-lighting PV system with a SEPIC converter for MPPT and battery charging. The converter has high conversion efficiency and shows high MPPT accuracy in various weathers. ASEPIC power-factor correction converter draws energy from the ac-line utility, preventing over-discharging of the battery. Experiment results of a laboratory proto type verified the feasibility of the proposed method.

Chiang *et al.* (2009) presented a PV battery charger implemented with a SEPIC converter. The SEPIC design used peak-current-mode control with the current command generated from the input PV voltage regulating loop where the voltage command was determined by both the PV module MPPT control loop and the battery- charging loop.

Comparison of various buck-boost converters are discussed by Chiang *et al.* (2009) through various points of view shows that among these converters, though SEPIC is not the best in terms of efficiency and cost, it still has the merits of non-inverting polarity, easy-to-drive switch and low input-current pulsation for a high-precision.

Tse *et al.* (2002) presented a novel technique for efficiently extracting maximum output power from a solar panel. APWMDC-DCSEPIC or Cuk converter operating in discontinuous inductor-current mode or capacitor- voltage mode matched the output resistance of the panel by injecting the switching frequency with a small sinusoidal-signal variation. The tracking capability was verified by anexperimentwitha1 0Wsolarpanel.

In order to obtain, the high efficient solar cell energy conversion, using SEPIC converter circuit board and implemented the fuzzy-control strategy with the ds PIC 30 F 4011 control chip. Control of PWM in an inverter decides the frequency, phase angle and potential at the turnout. Many researches analyses the performance of a three phase inverter using PI controller (Li and Wolfs, 2008).

To control the output voltage oscillations, in this study, fuzzy gain scheduling is proposed. Block diagram of the proposed system is shown in Fig. 1.

Basic function of sepic converter: Single-Ended Primary-Inductor Converter (SEPIC) is a type of DC-DC converter allowing positive regulated output voltage from an input voltage that varies from above to below the output voltage. SEPICs are useful in applications in which a battery voltage can be above and below that of the regulator's intended output.

Using a coupled inductor takes up less space on the PCB and tends to be lower cost than two separate inductors. The capacitor cs isolates the input from the output and provides protection against a shorted load. The basic converter and on time and odd time operations are as in Fig. 2-4.

For a SEPIC converter operating in a Continuous Conduction Mode (CCM), the duty cycle is given by:

$$D = \frac{V_{OUT} + V_D}{V_{IN} + V_{OUT} + V_D} \qquad (1)$$

VD is the forward voltage drop of the diode D1. The maximum duty cycle is:

$$D_{max} = \frac{V_{OUT} + V_D}{V_{IN(min)} + V_{OUT} + V_D} \qquad (2)$$

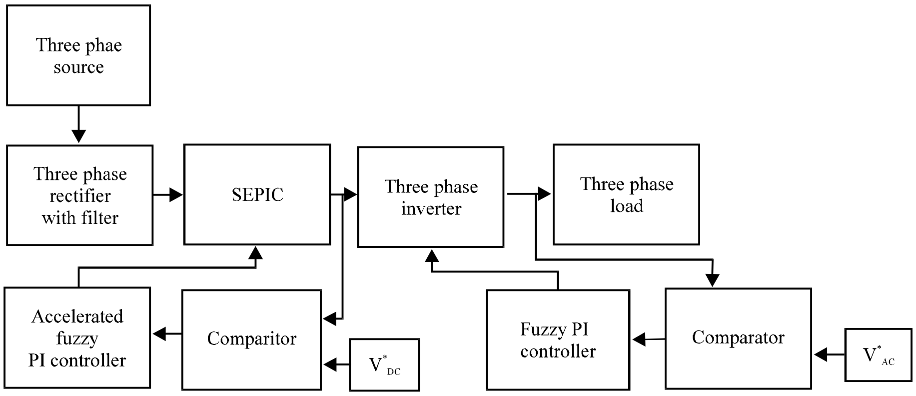

Fig. 1: Block diagram of proposed system

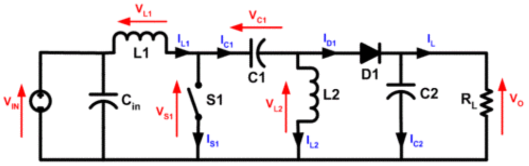

Fig. 2: SEPIC converter

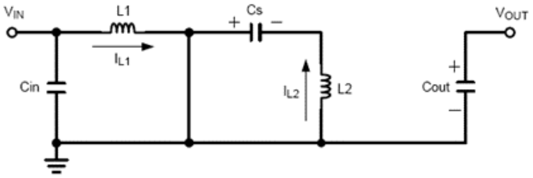

Fig. 3: SEPIC converter current flow during Q1 on-time

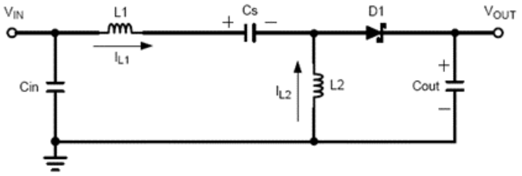

Fig. 4: SEPIC converter current flow during Q1 off-time

A good rule for determining the inductance is to allow the peak-to-peak ripple current to be Approximately 40% of the maximum input current at the minimum input voltage. The ripple current flowing in equal value inductors L1 and L2 is given by:

$$\Delta I_L = I_{IN} \times 40\% = I_{OUT} \times \frac{V_{OUT}}{V_{IN(min)}} \times 40\% \tag{3}$$

The inductor value is calculated by:

$$L1 = L2 = L \frac{V_{IN(min)}}{\Delta I_L \times f_{sw}} \times D_{max} \tag{4}$$

f_{sw} is the switching frequency and D_{max} is the duty cycle at the minimum V_{in}. The peak current in the inductor, to ensure the inductor does not saturate is given by:

$$I_{L1(peak)} = I_{OUT} \times \frac{V_{OUT} + V_D}{V_{IN}(\min)} \times \left(1 + \frac{40\%}{2}\right) \tag{5}$$

$$I_{L2(peak)} = I_{OUT} \times \left(1 + \frac{40\%}{2}\right) \tag{6}$$

If L1 and L2 are wound on the same core, the value of inductance in the equation above is replaced by 2L due to mutual inductance. The inductor value is calculated by:

$$L1' = L2' = \frac{L}{2} = \frac{V_{IN(min)}}{2 \times \Delta I_L \times f_{sw}} \times D_{max} \tag{7}$$

The selection of SEPIC capacitor, Cs, depends on the RMS current which is given by:

$$I_{cs(rms)} = I_{OUT} \times \sqrt{\frac{V_{OUT} + V_D}{V_{IN(min)}}} \tag{8}$$

The SEPIC capacitor must be rated for a large RMS current relative to the output power. This property makes the SEPIC much better suited to lower power applications where the RMS current through the capacitor is relatively small (relative to capacitor technology). The voltage rating of the SEPIC capacitor must be greater than the maximum input voltage. Tantalum and ceramic capacitors are the best choice for SMT having high RMS current ratings relative to size. Electrolytic capacitors work well for through-hole applications where the size is not limited and they can accommodate the required RMS current rating. The peak-to-peak ripple voltage on Cs (assuming no ESR):

$$\Delta V_{cs} = \frac{I_{OUT} \times D_{max}}{C_s \times f_{sw}} \tag{9}$$

A capacitor that meets the RMS current requirement would mostly produce small ripple voltage on Cs. Hence, the peak voltage is typically close to the input voltage. In a SEPIC converter when the power switch Q1 is turned on, the inductor is charging and the output current is supplied by the output capacitor. As a result, the output capacitor sees large ripple currents.

Thus, the selected output capacitor must be capable of handling the maximum RMS current. The RMS current in the output capacitor is:

$$I_{cout(rms)} = I_{OUT} \times \sqrt{\frac{V_{OUT} + V_D}{V_{IN(min)}}} \tag{10}$$

The ESR, ESL and the bulk capacitance of the output capacitor directly control the output ripple. As shown in Fig. 2-4 assume half of the ripple is caused by the ESR and the other half is caused by the amount of capacitance. Hence:

$$ESR \leq \frac{V_{ripple} \times 0.5}{I_{L1(peak)} + I_{L2(peak)}} \tag{11}$$

$$C_{OUT} \geq \frac{I_{OUT} \times D}{V_{ripple} \times 0.5 \times f_{sw}} \tag{12}$$

The output cap must meet the RMS current, ESR and capacitance requirements. In surface mount applications, tantalum, polymer electrolytic and polymer tantalum, or multi-layer ceramic capacitors are recommended at the output.

Similar to a boost converter, the SEPIC has an inductor at the input. Hence, the input current waveform is continuous and triangular. The inductor ensures that the input capacitor sees fairly low ripple currents. The RMS current in the input capacitor is given by:

$$I_{Cin(rms)} = \frac{\Delta I_L}{\sqrt{12}} \tag{13}$$

The input capacitor should be capable of handling the RMS current. Although the input capacitor is not so critical in a SEPIC application, a 10 iF or higher value, good quality capacitor would prevent impedance interactions with the input supply.

MATERIALS AND METHODS

Basic function of three phase inverter: In this study, three phase Hex bridge inverter is designed using six IGBTs. Three phase inverter is fed from DC-DC SEPIC converter. It is controlled by pulse width modulation. Fixed modulation index in PWM produces a constant potential difference when there is no change in load or in supplying voltage. But, the inverter voltage varies with regard to shift in load or change in input voltage. In this study input voltage is held constant with the help of accelerated fuzzy PI controlled SEPIC converter. The output voltage of an inverter is sensed controlled using a proposed fuzzy PI controller. Basic circuit of three phase inverter is shown in Fig. 5.

PI controller based inverter: The conventional PI controller is the simplest method of control and widely used in industries. Proportional plus integral controller increases the speed of reaction. It creates very low, steady state error. In this study, voltage error is passed as input to PI controller and output is accepted into the organization. General equation of the PI controller is:

$$U(s) = K_p E(s) + \frac{K_i}{s} E(s) \tag{14}$$

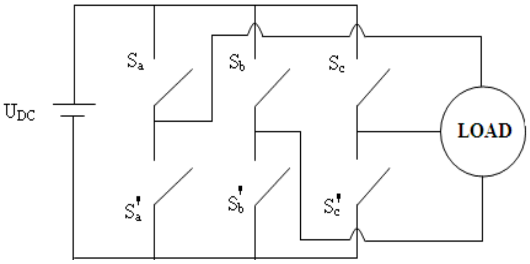

Fig. 5: Circuit of voltage source inverter

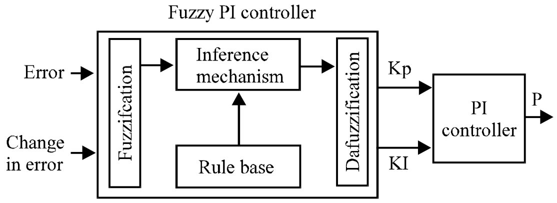

Fig. 6: Fuzzy PI controller block diagram the control algorithm of traditional PI controller can be described equally

Where:

K_p = Proportional gain
K_i = The integral gain
E(s) = The controller input and
U(s) = The controller output

Ziegler Nichols' method of tuning is adopted to determine the optimal value of KP and Ki values. But, the tour of this controller is, it produces high overshoot and long settling time.

Fuzzy PI controller based inverter: The fuzzy PI controller is designed by replacing the conventional PI controller. The fuzzy inference of fuzzy PI controller is based on the fuzzy rule table set previously. Hence, the algorithm of fuzzy inference reduces the complexity. The parameters of PI can be adjusted on-line which can be changed through the inquiry of fuzzy control rule table saved in the digital computer. The calculation voltage of the controller is very quick which can satisfy the rapid need of the controlled object. The block diagram of control system is shown in Fig. 6.

$$u(k) = k_p e(k) + k_i \sum e(k) \tag{15}$$

Where k_p is the proportional gain, k_i is the integral gain and e (k) is the voltage error. The design algorithm of fuzzy PI controller in this study is to adjust the k_p and k_i parameters online through fuzzy inference based on the current error (e) and change in error (ec) to make the control object in order to retrieve good dynamic and static performances.

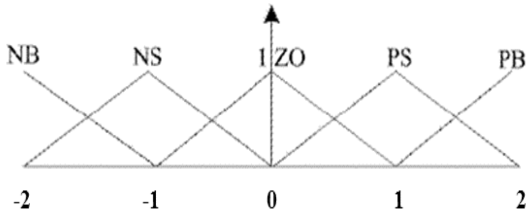

Fig. 7: Fuzzy membership functions of E and EC

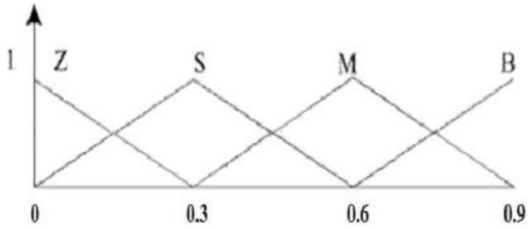

Fig. 8: Fuzzy membership functions of KP and KI

The input variables and output variables: Voltage error e and error change rate ec are used as fuzzy input and the proportional factor k_p the integral factor K_i are used as fuzzy outputs.

Fuzzy language of input and output variables: Input variables of fuzzy are E and EC whereas KP and KI are output variables. The fuzzy sets of E and EC are all specified as NB, NS, ZO, PS, PB, where NB, NS, ZO, PS and PB represent negative big negative small, zero, positive small and positive big respectively.

The fuzzy sets of KP and KI are defined as {Z, S, M, B}, where Z, S, M and B represent zero, small, medium and big (Kim and Oh, 2000). The membership functions of E, EC, KP and KI are triangular distribution functions. The membership functions for each variable are shown in Fig .7 and 8, respectively.

The rule of designing fuzzy rules is that the yield of the controller can cause the system output response dynamic and static performances as optimal. The fuzzy rules are generalized as Table 1 and 2 according to an expert experiment, on SEPIC converter system and simulation analysis of the organization. The Mamdani inference method is applied as the fuzzy inference mode. The inference can be penned as "IF A AND B THEN C". For instance":

- If (E is NB) and (Ec is NB) then (Kp is B) (Ki is Z)
- If (E is NB) and (Ec is ZO) then (Kp is B) (Ki is Z)
- If (E is ZO) and (Ec is NB) then (Kp is M) (Ki is B)
- If (E is PB) and (Ec is NB) then (Kp is M) (Ki is Z)

Table 1: Control rules for KP

Kp		Ec				
		NB	NS	ZO	PS	PB
	NB	B	B	B	B	M
	NS	M	B	S	S	S
	ZO	M	B	Z	S	B
	PS	S	S	S	S	S
E	PB	M	B	B	M	B

Table 2: Control rules for KI

Kp		Ec				
		NB	NS	ZO	PS	PB
	NB	B	B	B	B	M
	NS	M	B	S	S	S
	ZO	M	B	Z	S	B
	PS	S	S	S	S	S
E	PB	M	B	B	M	B

KP and KI are written the same as 25 fuzzy condition statements (Wang *et al*., 2007). The output variable can be obtained by the MIN-MAX inference. The centroid method is adopted for defuzzification.

Accelerated fuzzy pi controller based sepic converter: The controller defines the duty ratio of switching pulse. Since, the output voltage of converter depends on the duty ratio, controller decides the output potential. In this study three phase source followed by the rectifier feeds the SEPIC converter.

The required output voltage is set as reference voltage and it is compared with the actual voltage feedback from the converter. It is taken as voltage error which is considered as input to the accountant. In this study accelerated fuzzy PI controller is proposed to control the SEPIC converter.

The accelerated fuzzy PI controller is a modified, improved version of the fuzzy PI controller for the improvement of transient response of the system. The fuzzy PI controller uses only two inputs-voltage error (e) and rate of change of voltage Error (EC). But, in this model, an additional input named 'accelerated rate of change of error (acc) is used to improve the transient response of the system (Viswanathan *et al*., 2002).

With these three inputs the structure of the FLC is composed of two independent parallel fuzzy control blocks, each of which supports the corresponding fuzzy control rules and a defuzzifier. The incremental output of the FLC is formed by algebraically adding the end products of the two fuzzy control blocks. Block diagram of the pattern is shown in Fig. 9. In each fuzzy controller, rules are the same as stated in Table 1 and 2. Only the inputs are varied.

Simulation results and discussion: The total scheme is simulated using MATLAB/Simulink. A simulation model of the system is shown in Fig.10.

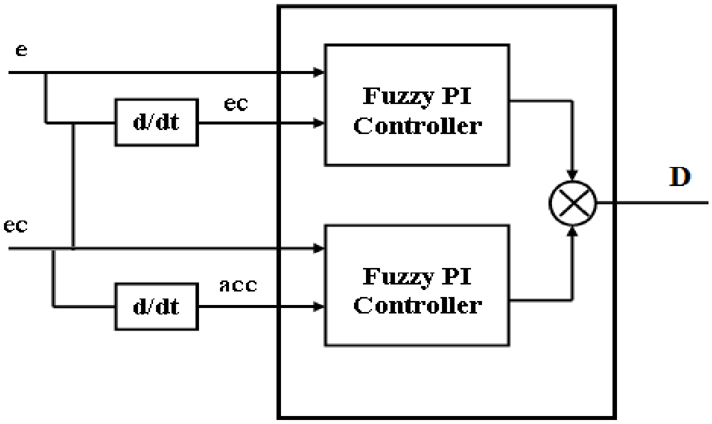

Fig. 9: Accelerated fuzzy PI controller block diagram

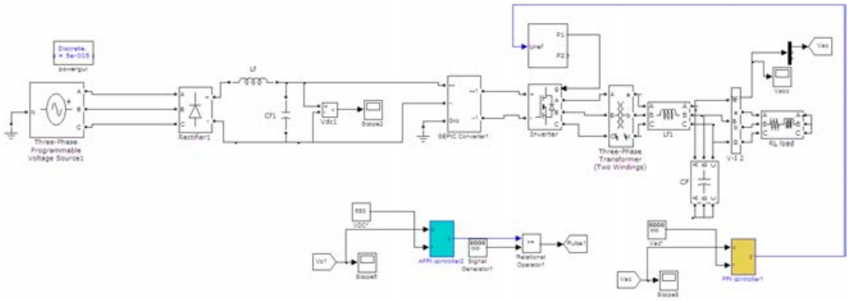

Fig. 10: Simulation model of the proposed system

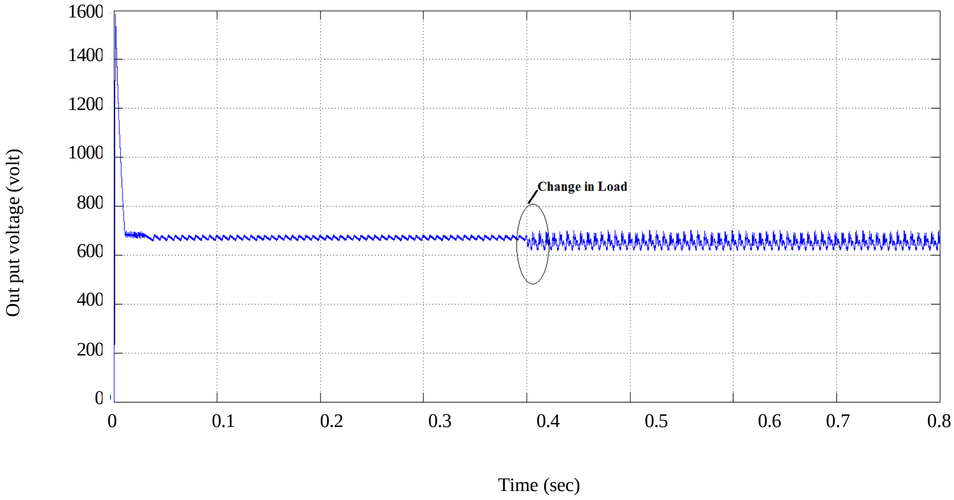

Fig. 11: The output voltage of AFPI controlled DC-DC SEPIC converter with variable load

RESULTS AND DISCUSSION

To analyze the system performance DC-DC SEPIC converter, load is suddenly increased. It causes a potential fall in case of absence of a controller. The application of controller in the aspect of voltage stability is analyzed. The organization is analyzed using proposed accelerated fuzzy PI controller with the same loading condition as in case of PI controller. Figure 11 shows the voltage output of the accelerated fuzzy PI controlled SEPIC converter.

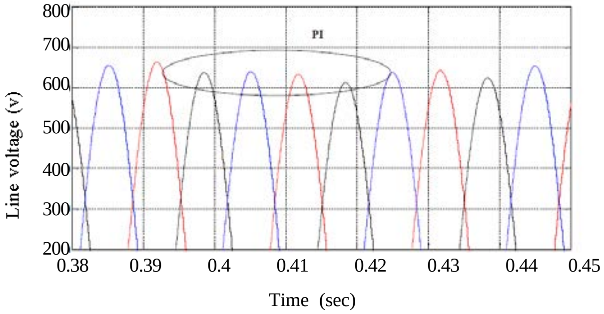

Fig. 12: Three phase output voltage with PI controller

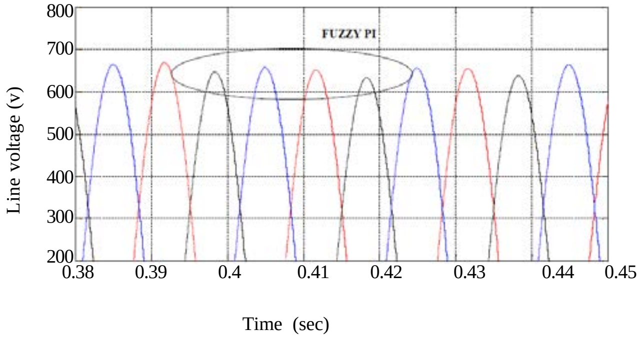

Fig. 13: Three phase output voltage with Fuzzy PI controller

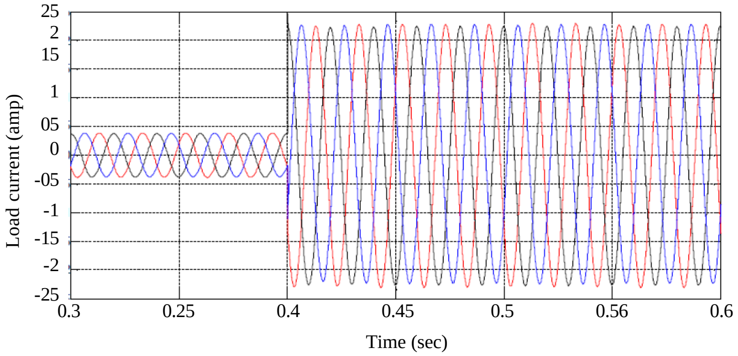

Fig. 14: Three phase Load current with Fuzzy PI controller

Table 3: Performance alanysis of accelerated fuzzy control with PI controller for SEPIC converter

Parameter	PI controller	Accelerated fuzzy controller
Peak overshoot	High	Medium
Steady state error (%)	4.15	1.5
Voltage ripple during steady state (%)	4.71	2.8
Voltage ripple during dynamic state (%)	13.8	11.9

From the graph it is mentioned that voltage stability is improved by the application of accelerated fuzzy PI controller. Table 3 presents the performance comparison of accelerated fuzzy PI controller based DC-DC SEPIC converter with PI controller.

Table 3, it is clear that accelerated fuzzy PI controller based DC-DC converter performs well during steady state as well as in a dynamic state.

To examine the operation of three phase inverter with resistance emulation initial system is analyzed with PI controller. Figure 12 depicts the three phase output voltage with PI controller.

From Fig. 9, it is obvious that the PI controller produces some oscillation during a change in load. To defeat this proposed fuzzy PI controller is analyzed. performance three phase output voltages and current with variable load using the fuzzy PI controller are pictured in Fig. 13 and 14.

Voltage oscillation during dynamic state using PI controller is 3%. Fuzzy PI controller in the proposed system produces it in the range of 1.8%. From the simulation results it is inferred that the proposed system makes quality voltage leads quality power.

CONCLUSION

Closed loop DC-DC converter and inverter is analyzed in this study provides quality power and voltage which is mandatory for all electricity consumers. The enhancement of quality in voltage results quality power. In a dynamic state PI controlled SEPIC converter provides reduced ripple but it produces high overshoot and steady state error comparatively. The proposed accelerated fuzzy PI controller overcomes these problems. It produces less voltage ripple in a steady state as well as in a dynamic state. Peak overshoot is less compared to PI controller; it offers the merit of reduced voltage stress in the switching device of the power converter. Reduced steady state error and voltage stress, improves the performance of load. Hence, from the analysis, it is obvious that accelerated fuzzy PI controller based SEPIC converter is compact, effective and cost effective and provides quality voltage. PI controlled inverter provides good performance such as less overshoot at the time of starting. During dynamic state voltage is oscillated using PI controller. The proposed fuzzy PI controlled inverter provides better performance during steady state as well as in a dynamic state.

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